Minimization of Real Power Loss and Augmentation of Static Voltage Stability Margin by Enhanced Algorithm

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Abstract

This paper presents a new Enhanced African Wild Dog Algorithm (EAWDA) for solving the multi-objective reactive power dispatch problem. Inspired by Basic African wild dog algorithm (AWDA), this paper progresses by adding rounding up behaviours of wild dog, The proposed (EAWDA) algorithm has been tested on standard IEEE 30 bus test system and simulation results shows clearly about the noble performance of the projected algorithm.

***Key words**: Modal analysis, optimal reactive power, Transmission loss, African Wild Dog Algorithm.*

1. Introduction

The main objective of the optimal reactive power dispatch is to maintain the level of voltage and reactive power flow within the specified limits under various operating conditions and network configurations. By utilizing a number of control tools such as switching of shunt reactive power sources, changing generator voltages or by adjusting transformer tap-settings the reactive power dispatch can be done. By doing optimal adjustment of these controls in different levels, the redistribution of the reactive power would minimize transmission losses. This procedure forms an optimal reactive power dispatch problem and it has a major influence on secure and economic operation of power systems. Various mathematical techniques like the gradient method [1,2] Newton method [3]and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods has the difficulty in handling inequality constraints. If linear programming is applied then the input- output function has to be expressed as a set of linear functions which mostly lead to loss of accuracy. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Enhancing the voltage stability, voltage magnitudes within the limits alone will not be a reliable indicator to indicate that, how far an operating point is from the collapse point. The reactive power support and voltage problems are internally related to each other. This paper formulates by combining both the real power loss minimization and maximization of static voltage stability margin (SVSM) as the objectives. Global optimization has received extensive research attention, and a great number of methods have been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem[9,10].Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [11], by using Genetic algorithm optimal reactive power flow has been solved, and the main aspect considered is network security maximization. In [12] is proposed to improve the voltage stability index by using Hybrid differential evolution algorithm. In [13] Biogeography Based algorithm proposed to solve the reactive power dispatch problem. In [14] a fuzzy based method is used to solve the optimal reactive power scheduling method and it minimizes real power loss and maximizes Voltage Stability Margin. In [15] an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16] the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17] a standard algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits .In [18] proposed a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19] a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20] is presented a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads.On the basis of the research on African wild dogs' predation, the paper [21] introduces a meta-heuristic African wild dog algorithm (AWDA) to solve engineering optimization problems. In order to prevent AWDA from falling in local optimum and keep it more in line with the behaviour of the African wild dog hunting, this paper progresses AWDA by accumulating the rounding up behaviours called as Enhanced African Wild Dog Algorithm (EAWDA) and its effectiveness compared with other algorithms. Proposed method EAWDA been evaluated in standard IEEE 30 bus test system & the simulation results shows that our proposed approach outperforms all reported algorithms in minimization of real power loss and voltage stability index .

2. Voltage Stability Evaluation

2.1.Modal analysis for voltage stability evaluation

Modal analysis is one among best methods for voltage stability enhancement in power systems. The steady state system power flow equations are given by.

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_{p\theta} & J_{pv}\\ J_{q\theta} & J_{QV}\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V\end{bmatrix} \quad (1)$$

Where

ΔP = Incremental change in bus real power.

ΔQ = Incremental change in bus reactive Power injection

Δθ = incremental change in bus voltage angle.

ΔV = Incremental change in bus voltage Magnitude

Jpθ , JPV , JQθ , JQV jacobian matrix are the sub-matrixes of the System voltage stability is affected by both P and Q.

To reduce (1), let ΔP = 0 , then.

$$\Delta Q = \left[J_{QV} - J_{Q\theta}J_{P\theta^{-1}}J_{PV}\right]\Delta V = J_R\Delta V \quad (2)$$

$$\Delta V = J^{-1} - \Delta Q \quad (3)$$

Where

$$J_R = \left(J_{QV} - J_{Q\theta}J_{P\theta^{-1}}JPV\right) \quad (4)$$

J_R is called the reduced Jacobian matrix of the system.

2.2. Modes of Voltage instability:

Voltage Stability characteristics of the system have been identified by computing the Eigen values and Eigen vectors.

Let

$$J_R = \xi\wedge\eta \quad (5)$$

Where,

ξ = right eigenvector matrix of JR

η = left eigenvector matrix of JR

$\wedge$ = diagonal eigenvalue matrix of JR and

$J_{R^{-1}} = \xi\wedge^{-1}\eta(6)$

From (5) and (8), we have

$\Delta V = \xi\wedge^{-1}\eta\Delta Q(7)$

or

$\Delta V = \sum_I \frac{\xi_i\eta_i}{\lambda_i}\Delta Q(8)$

Where ξi is the ith column right eigenvector and η the ith row left eigenvector of JR.

λi is the ith Eigen value of JR.

The ith modal reactive power variation is,

$\Delta Q_{mi} = K_i\xi_i$ (9)

where,

$K_i = \sum_j \xi_{ij^2} - 1(10)$

Where

ξji is the jth element of ξi

The corresponding ith modal voltage variation is

$\Delta V_{mi} = [1/\lambda_i]\Delta Q_{mi}(11)$

If | λi | =0 then the ith modal voltage will collapse .

In (10), let ΔQ = ek where ek has all its elements zero except the kth one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} \qquad (12)$$

η_{1k} k th element of η_1

V –Q sensitivity at bus k

$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1}(13).$

3. Problem Formulation

The objectives of the reactive power dispatch problem is to minimize the system real power loss and maximize the static voltage stability margins (SVSM).

3.1. Minimization of Real Power Loss

Minimization of the real power loss (Ploss) in transmission lines is mathematically stated as follows.

$P_{loss=} \sum^{n}_{\substack{k=1\\k=(i,j)}} g_{k(V_i^2+V_j^2-2V_iV_j\ \cos\theta_{ij})}$ (14)

Where n is the number of transmission lines, gk is the conductance of branch k, Vi and Vj are voltage magnitude at bus i and bus j, and θij is the voltage angle difference between bus i and bus j.

3.2. Minimization of Voltage Deviation

Minimization of the voltage deviation magnitudes (VD) at load buses is mathematically stated as follows.

Minimize VD = $\sum_{k=1}^{nl} |V_k - 1.0|$ (15)

Where nl is the number of load busses and Vk is the voltage magnitude at bus k.

3.3. System Constraints

Objective functions are subjected to these constraints shown below.

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i \sum_{j=1}^{nb}} V_j \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (16)$$

$$Q_{Gi} - Q_{Di} - V_{i \sum_{j=1}^{nb}} V_j \begin{bmatrix} G_{ij} & \sin\theta_{ij} \\ +B_{ij} & \cos\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (17)$$

where, nb is the number of buses, PG and QG are the real and reactive power of the generator, PD and QD are the real and reactive load of the generator, and Gij and Bij are the mutual conductance and susceptance between bus i and bus j.

Generator bus voltage (VGi) inequality constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \quad (18)$$

Load bus voltage (VLi) inequality constraint:

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \quad (19)$$

Switchable reactive power compensations (QCi) inequality constraint:

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \quad (20)$$

Reactive power generation (QGi) inequality constraint:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \quad (21)$$

Transformers tap setting (Ti) inequality constraint:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt \quad (22)$$

Transmission line flow (SLi) inequality constraint:

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \quad (23)$$

Where, nc, ng and nt are numbers of the switchable reactive power sources, generators and transformers.

4. African Wild Dog Algorithm

African wild dogs mainly live in dry grasslands and semi-deserts in Africa, active in grasslands, savanna and open dry scrub. They live in packs and occupy territories ranging from 200 to 2000 square kilometres. African wild dogs hunt medium-sized ungulates in cooperative packs, locating by vocalizing. They can run long distances, at speeds up to about 45 kilometres per hour. African wild dogs live in packs of 40 members (including 7-15 adults) that are usually dominated by a monogamous breeding pair. They are good at cooperation and led by the male leader when hunting in their territory. They depend rather on the sense of sight than smell and pursue their prey in a long, open chase until the prey is exhausted. African wild dogs contact with each other in various ways such as smell (olfactory), voice and posture (body language). They have a very strong odour, so that they can easily detect other group members in the distance. Members of a pack vocalize to help coordinate their movements. Its voice is characterized by an unusual chirping or squeaking sound, similar to a bird. African wild dog algorithm (AWDA) [21] is raised by using an iterative manner to simulate their group hunting behaviours, i.e., to find the optimal value. African wild dogs solve the optimization problem through the steps of initializing dog's position, competing for head dog and collaborative moving.

5. Enhanced African Wild Dog Algorithm (EAWDA) for reactive power problem

Step1: Initializing optimization problems and algorithm parameters.

Step2: Randomly initialize wild dog packs, so that the initial position of wild dogs can fill the entire solution space as far as possible.

Step3: Solving the fitness function value for each wild dog and sort the wild dogs accordingly.

Step4: Collaborative moving. In this step the *i* th wild dog moves with a certain probability toward *j* wild dog who has a higher fitness function value. The new position of *i* wild dog after moving is:

$$x_{i,new} = x_i + rand(x_i - x_j) \times E \times \left(\frac{G}{H}\right) \quad (24)$$

Where rand is an arbitrary value in the range, E represents iteration step coefficient: E=1-(Iteration number/Max iteration),G is the average Euclidean distance of all wild dogs and H is the Euclidean distance between wild dog *i* and wild dog *j*.

Step5: When hunting in packs, members of a pack vocalize to help coordinate their movements. As soon as they find prey, African wild dogs quickly gather to the head dog and round up the prey. When solving the objective function value, for this behaviour, generates an arbitrary numberA_θ within range [0, 1].

If $A_\theta$is bigger than the preset threshold value, then wild dog *i* moves to the prey. Otherwise, it doesn't move and directly goes into the next iteration. The updated position x_i^{t+1} is:

$$x_i^{t+1} = \begin{cases} x_i^t r_m < \theta \\ x_j + arbitrary \times ra \quad r_m > \theta \end{cases} \quad (25)$$

Where ra: is rounding up step length,x_j is the position of head dog and $x_i^t$is the current position of the *i* th wild dog in the *t* th iteration. Since the positions of some African wild dogs after rounding up may not be within the search space, the updated positions need trans-border processing.

In this reactive optimization problem, in order to make more precise solving, rounding up has been set & in turn step length decreases with increasing iteration times. Then the update equation is as follows:

$$ra(t) = (x_{imax} - x_{imin}) \times exp(-Maxgen(t)) \quad (26)$$

Where $Maxgen(t)$represents the *t*th iteration *t.*

Step 6: Repeat step3 to step5 till it reaches the maximum of iteration or accuracy of the algorithm.

6. Simulation Results

The efficiency of the proposed EAWDA method is demonstrated by testing it on standard IEEE-30 bus system. The IEEE-30 bus system has 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results have been presented in Tables 1, 2, 3 &4. And in the Table 5 shows the proposed algorithm powerfully reduces the real power losses when compared to other given algorithms. The optimal values of the control variables along with the minimum loss obtained are given in Table 1. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table 1. Results of EAWDA – ORPD optimal control variables

Control variables	Variable setting
V1	1.031
V2	1.039
V5	1.036
V8	1.029
V11	1.001
V13	1.027
T11	1.00
T12	1.00
T15	1.01
T36	1.01
Qc10	2
Qc12	2
Qc15	3
Qc17	0
Qc20	2
Qc23	3
Qc24	3
Qc29	2
Real power loss	4.2872
SVSM	0.2479

Optimal Reactive Power Dispatch together with voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized simultaneously. Table 2 indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the voltage stability index has increased from 0.2479 to 0.2486, an advance in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The Eigen values equivalents to the four critical contingencies are given in Table 3. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

Table 2.Results of EAWDA -Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

Control Variables	Variable Setting
V1	1.034
V2	1.038
V5	1.040
V8	1.031
V11	1.003
V13	1.030
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	3
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9872
SVSM	0.2486

Table 3. Voltage Stability under Contingency State

Sl.No	Contingency	ORPD Setting	VSCRPD Setting
1	28-27	0.1412	0.1425
2	4-12	0.1639	0.1649
3	1-3	0.1760	0.1771
4	2-4	0.2020	0.2040

Table 4. Limit Violation Checking Of State Variables

State variables	limits		ORPD	VSCRPD
	Lower	upper		
Q1	-20	152	1.3422	-1.3269
Q2	-20	61	8.9900	9.8232
Q5	-15	49.92	25.920	26.001
Q8	-10	63.52	38.8200	40.802
Q11	-15	42	2.9300	5.002
Q13	-15	48	8.1025	6.033
V3	0.95	1.05	1.0372	1.0392
V4	0.95	1.05	1.0307	1.0328
V6	0.95	1.05	1.0282	1.0298
V7	0.95	1.05	1.0101	1.0152
V9	0.95	1.05	1.0462	1.0412
V10	0.95	1.05	1.0482	1.0498
V12	0.95	1.05	1.0400	1.0466
V14	0.95	1.05	1.0474	1.0443
V15	0.95	1.05	1.0457	1.0413
V16	0.95	1.05	1.0426	1.0405
V17	0.95	1.05	1.0382	1.0396
V18	0.95	1.05	1.0392	1.0400
V19	0.95	1.05	1.0381	1.0394
V20	0.95	1.05	1.0112	1.0194
V21	0.95	1.05	1.0435	1.0243
V22	0.95	1.05	1.0448	1.0396
V23	0.95	1.05	1.0472	1.0372
V24	0.95	1.05	1.0484	1.0372
V25	0.95	1.05	1.0142	1.0192
V26	0.95	1.05	1.0494	1.0422
V27	0.95	1.05	1.0472	1.0452
V28	0.95	1.05	1.0243	1.0283
V29	0.95	1.05	1.0439	1.0419
V30	0.95	1.05	1.0418	1.0397

Table 5. Comparison of Real Power Loss

Method	Minimum loss (MW)
Evolutionary programming[22]	5.0159
Genetic algorithm [23]	4.665
Real coded GA with Lindex as SVSM [24]	4.568
Real coded genetic algorithm [25]	4.5015
Proposed EAWDA method	4.2872

7. Conclusion

In this paper, proposed EAWDA has been successfully implemented to solve optimal reactive power dispatch (ORPD) problem. The main advantages of EAWDA when applied to the ORPD problem is optimization of different type of objective function, i.e real coded of both continuous and discrete control variables, and without difficulty in handling nonlinear constraints. Proposed EAWDA algorithm has been tested on the IEEE 30-bus system. Simulation Results clearly show the good performance of the proposed algorithm in reducing the real power loss and enhancing the voltage profiles within the limits.

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